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STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE GEOLOGICAL SURVEY
FRANK W. DeWOLF, Chief

Cooperative Mining Series
BULLETIN 24

WATER-GAS OPERATING METHODS WITH CENTRAL DISTRICT BITUMINOUS COALS AS GENERATOR FUEL

A Summary of Experiments on a Commercial Scale
A Preliminary Report

BY
W. A. DUNKLEY, State Geological Survey Division
and
W. W. ODELL, U. S. Bureau of Mines

ILLINOIS MINING INVESTIGATIONS
Prepared under a cooperative agreement between the Illinois State Geological Survey Division, the Engineering Experiment Station of the University of Illinois, and the U. S. Bureau of Mines

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URBANA, ILLINOIS
1919

ILLINOIS MINING INVESTIGATIONS

Cooperative Agreement

GAS SECTION

The difficulty, due to war conditions, of obtaining adequate and reliable delivery of eastern gas-coal and of coke has suggested the wider use in gas manufacture of low-sulphur coal mined in the central district, comprising Illinois, Indiana, and western Kentucky.

The needs of the gas industry, and the desire of the U. S. Fuel Administration to meet those needs, has led to the appointment by Governor Frank O. Lowden, of a Technical Committee on Gas, By-products, and Public Utilities, to act in an advisory relation. The committee includes representatives of the Illinois Gas Association, the U. S. Bureau of Mines, the Engineering Experiment Station of the University of Illinois, and the State Geological Survey Division of the Department of Registration and Education, State of Illinois.

Previously, some studies of the use of Illinois coal in retort-gas manufacture and in by-product coke ovens, and of the chemical and physical properties of Illinois coal, have been conducted under the Illinois Mining Investigations, cooperative agreement—a joint agency of the U. S. Bureau of Mines, the University of Illinois, and the State Geological Survey Division. The continuation and expansion of this work has been recommended by the Technical Committee and the Fuel Administration. In response a Gas Section has been created, and experienced gas engineers, chemists, and other specialists have undertaken a program of experiment on a commercial scale to extend the use of central district coal in water-gas generators and in gas retorts.

The results of the investigations will be published, and, in addition, the operators of gas plants in the region naturally tributary to
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STATE OF ILLINOIS
DEPARTMENT OF REGISTRATION AND EDUCATION

DIVISION OF THE
STATE GEOLOGICAL SURVEY
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WATER-GAS OPERATING METHODS WITH CENTRAL DISTRICT BITUMINOUS COALS AS GENERATOR FUEL—NOTES ON EXPERIMENTS ON A COMMERCIAL SCALE.

By W. A. Dunkley
and W. W. Odell

INTRODUCTION.

During last July a survey was made of the gas plants of Illinois and neighboring states, to determine what progress and economies had been made in the use of the coals of this region in gas manufacture. The facts learned from this inspection were published in Bulletins 21 and 22 of this series, the former bulletin dealing with the use of these coals in the manufacture of retort-coal gas, and the latter with their use as water-gas generator fuel.

Although considerable progress had been made, and some operators were realizing a considerable saving from the use of these coals, it was concluded from this inspection that much was yet to be learned about the use of central district coals in both processes, but it was thought that the greatest amount of useful information could be obtained in a short time by further experimentation on the water-gas process. Accordingly it was decided to carry out a series of experiments, on a commercial scale, to determine the possibilities of the process, its limitations, available fuels, suitable methods of operation, and the effects of many of the variable conditions entering into water-gas manufacture.

Through the courtesy of the Public Service Company of Northern Illinois, the facilities of the Streator plant were extended for experimentation. This plant was chosen because it is well equipped, and because its generating capacity is sufficiently large so that any errors in judgment or mistakes in the early stages of the experimental work would not jeopardize the gas supply to the city. Also the experiments, while conducted on a commercial scale, would not involve the useless expenditure of as much money on coals, some of which might prove unsuitable, as would be necessary in a larger plant.

During the course of the experiments, which extended over a period of about four months, many analyses were made of the gases produced during the different stages of operation and under various operating conditions. Other observations were also made, and it is hoped that the publication and discussion of these in a later bulletin will throw more light on the process and lead to further studies. The present paper is preliminary to the main publication, and is designed to furnish operating information to the managers and superintendents of water-gas plants, without going in detail into the mass of data upon which the conclusions are based.

PROBLEMS AND THEIR SOLUTION.

The superintendent who contemplates the use of bituminous coal for water-gas generator fuel is confronted by the following problems, some of which apply more strongly in certain cases than in others: the education of gas makers in the use of coal fuel and the overcoming of their prejudices against it; the selection of suitable coal; the control of arching and caking in the generator; the maintenance of production capacity with coal fuel; the prevention of an excessive amount of smoke during operation; the prevention of sticking of valves, due to tar deposits; and the control of clinker formation.

Some of the problems enumerated could, perhaps, be solved by the same methods in one plant as in another, but others require individual treatment on account of certain peculiarities of existing conditions in particular plants. It is obvious that the methods developed in one particular plant under one set of conditions cannot apply to all. It is the purpose of this paper to discuss the principles governing operation briefly, to tell the reasons why certain operating methods were adopted, and what the results were in the case described.

These problems will be discussed under the following heads:

1. Securing the cooperation of gas makers.
2. Use of coal and coke mixtures.
3. Selection of coal.
4. Control of arching and caking of coal in the generator.
5. Reduction of production capacity with coal fuel, with the usual operating methods.
6. The blow-run cycle for increasing capacity.
7. The blow-run with mixed coal and coke.
8. The air purge.
9. Smoke prevention.
10. Prevention of sticking of valves.
11. Control of clinker.

1. Securing the Cooperation of Gas Makers

Of the problems mentioned, the first is often the most difficult one to solve. The uncertainty of the results to be obtained with an unknown fuel, the lack of a financial incentive to undertake something which is new and untried, and which may lead to difficulties or inconveniences, are sufficient to prejudice many gas makers, even before a trial is made.

The superintendent who is about to try a new fuel, and especially a fuel so different from the customary as is bituminous coal, must fit his method of attack to the temperament of his operators. Different methods must be used in different cases. It must be realized that the cooperation of the gas maker must be obtained for good results. A good gas maker senses the behavior of his machine in a manner incomprehensible to the mere technical man, and this peculiar understanding can be utilized to advantage if at the same time the more visible conditions are kept sight of carefully.

It is not the purpose of this paper to tell the superintendent how to handle his men, but merely to suggest how essential to success is their cooperation. It is believed that this can be obtained in any way which makes them feel that it is to their interest to succeed, or that they are believed to be capable of accomplishing something out of the ordinary.

2. Use of Coal and Coke Mixture

In starting the use of coal fuel in a plant where it has never been tried, the writers are of the opinion that it is preferable for operators to accustom their gas makers gradually to the new conditions by running for a time with a mixture of coal and coke, and gradually increasing the percentage of coal. In this way the operating conditions may be changed gradually and 100 per cent coal used eventually with little difficulty.

In case the production capacity of a plant is barely sufficient to carry the load with straight coal, it will usually be found that the capacity may be increased materially, either by the use of a coal and coke mixture, or, if plant conditions will permit, by the adoption of the blow-run cycle which will be described later. The mixture of a small percentage of coke with the coal makes the fire more permeable to the blast, thereby permitting more air to pass through the fire in a given time with the same blast pressure. In the Streator tests about 12 per cent more blast passed the fire with a mixture containing 75 per cent coal than with 100 per cent coal. This practice results in a higher fuel-bed temperature and a consequent larger make during the steam run.

Usually it is not necessary to begin with a very small percentage of coal. A half and half mixture can usually be employed from the start without difficulty. Since coke is considerably more expensive than coal, the operator who desires to make as great a saving as possible consistent with his operating conditions, will finally use the smallest amount of coke in the mixture that will permit him to get the necessary capacity from his machine. In the tests at Streator the results over a long period indicated that a larger output per hour of operating time could be obtained from a mixture containing 70 to 80 per cent coal than from mixtures containing either more or less coal.

While mixtures of coal and coke offer some advantages in increasing machine capacity, somewhat more oil is required to maintain a given heating value than with straight coal. This increase may amount to between 0.1 and 0.2 gallon of oil per 1,000 cubic feet of finished gas with 25 per cent of coke in the mixture. The generator fuel during the Streator test was about three to four pounds per 1,000 less with the mixture than with straight coal. However, on account of the different rates of burning of coal and coke during lay-over periods, this difference might not be found in a plant operating practically continuously. The steam per 1,000 cubic feet was about five pounds greater with the mixed fuel.

A coal and coke mixture, without a blow-run, may be used in one of two ways, according to the results desired. All the coke may be charged into the machine during the first part of the day's run, or it may be mixed with the coal in each charge. The first method gives a quicker start, and the subsequent running is practically on straight coal. With the other method the start is not so quick, but the average hourly make will usually be greater and more uniform. Or the operator may combine the two methods, making the first charges chiefly coke and the later charges chiefly coal. Which method is desirable will probably depend upon the local conditions, as length of operating time, for example.

3. Selection of Coal

In selecting a central district coal for use as generator fuel many of the same considerations apply as with other fuels for this purpose. The coal should not break up too much on handling and it should be as free as possible from ash. The sulphur content is also a very important consideration. While analyses of the coals used in Streator are not yet completed, the indications are that at least one-fourth of the sulphur present in the coal passes into the blue gas. For example, a coal containing about 1.57 per cent S gave 155 grains H_2S per 100 cubic feet in the blue gas. The Texas oil used brought this up to 200 grains in the unpurified carburetted gas. Probably the form in which the sulphur is present in the coal has a marked effect on the amount transmitted to the gas. It is hoped that a further study of this relation may be discussed in the main report. In general it seems probable that any plant which is not equipped to purify raw gas containing more than 200 grains of H_2S per 100 cubic feet at the average rate of purification, should insist on a sulphur content not exceeding 1.50 per cent in the delivered coal. Bulletin No. 23 of this series gives a list of the mines of the central district which could probably furnish coal meeting the above condition.

As with the other fuels the size of coal required for water-gas manufacture is important. Since nearly all central district coals show the coking property in varying degrees, it is not possible to prescribe one best size for all coals.

The stronger the coking property of a coal, the greater is the tendency for the lumps to mat together in the fire. The effect of this is similar to the conditions existing when a coal containing considerable slack is used. In the experiments at Streator, large egg size (4 to 6 inches) gave satisfactory results. Some of the coals used broke up more readily than others, so that there was considerable slack present in some cases. While under favorable conditions of blast pressure, etc., it is possible to use coal containing considerable slack, its effect in obstructing the passage of air through the fire is detrimental; and careful forking and the avoidance of unnecessary breakage in handling are therefore recommended.

Some central district coals tend to disintegrate somewhat during storage, especially if exposed to the weather. Since the size is of considerable importance in water-gas operation, it seems inadvisable to store coal for this purpose longer than necessary to maintain an adequate stock. When necessary to store such coal, it may be advisable to purchase a larger size than otherwise required, in order to make due allowance for disintegration and breakage. The larger sizes are also less liable to spontaneous ignition.

4. Control of Arching and Caking of Coal in the Generator

For successful operation with coal, the method of procedure must be different from that with coke, else trouble is likely to be speedily encountered. Coke in the generator presents a porous loose mass to the passage of air and gases through the fire, while on the other hand, most bituminous coals tend when freshly charged to cake and run together. This caking, if excessive, is evidenced by an increase in the blast pressure under the grate, other conditions remaining the same, and if the set is equipped with an air meter in the generator blast line, a decided decrease in the amount of air going through the fire will be indicated soon after making a fresh coaling. This is especially true when excessively heavy charges are made. It is frequently customary in plants operating with coke to make at the beginning of the day's run, one or more fuel charges of two or three times the size of the normal running charge which is made after the fuel bed is up to its usual operating depth. With the usual bituminous coal this procedure would almost certainly lead to trouble. In general, it may be said that large egg-size coal, even with the caking controlled, offers more resistance to the passage of air than does coke, and the addition of a large charge of green coal causes an excessive increase in this resistance. The fuel on caking forms a nearly impenetrable arch over the fire, which hinders the passage of air. This slows up the combustion during the blast period, decreases the temperature of the fuel bed, and results in a great decrease in the amount of gas produced during the run period. This arching frequently remains in the place where formed, even after the already coked fuel beneath it has burned away, leaving a hollow space between. The arching may be so tenacious that it is necessary to break it up with bars before another coal charge can be added. This, of course, is unwelcome labor, even were it not an indication of an unhealthy operating condition.

The prevention of arching can be readily accomplished by making charges of normal size and with greater frequency during the early part of the day's run. At Streator it was the practice to make one run in the morning before coaling; the reason for this will be discussed later. A normal charge was added after the first run, another after the third run, and this method was continued until the fire was up to its usual operating level even with the bottom of the take-off connection, as with coke. After this the depth of fire was maintained by normal size charges about 35 to 45 minutes apart. The weight of these charges was about the same as the weight of the

normal charge when using coke. It was found that by this method of charging the resistance to the passage of air through the fire was not excessive, the fire burned down uniformly, and there was no arching, and consequently barring down was no longer necessary. Where a coal with very strong coking properties is used and arching persists even under the above conditions, the difficulty can be remedied by making smaller but more frequent charges, though this necessitates opening the generator more frequently, and causes a certain loss of operating time. In many plants the loss of time during coaling is excessive and could be considerably reduced by carefully arranging the movements of the various men participating in the operation. It will usually be found, however, that the time required for coaling with central district coals is no greater than with coke.

It was formerly believed by some operators that in using bituminous coal as generator fuel, the volatile matter would be largely driven off from a fresh charge during the first blast after coaling. Contrary to this, it is found that the surface of the fuel bed remains fairly cool from charge to charge. The surface of a charge has not been entirely converted into coke when the next charge is added. The rate of conversion into coke will of course depend upon the temperature obtained in the generator which in turn is dependent upon the amount of air passed through the fire during the blast period and the amount of steam used during the run. On one occasion a 6-inch lump of coal removed from the fire just before making a fresh charge showed about ¾ inch of coking on each face, perpendicular to the laminations of the coal; while the other two faces had coked to a depth of about ¼ inch.

The fact that the surface of the fuel usually remains relatively cool often causes delay in the ignition of the generator gases when the lid is opened for charging. These gases are usually combustible and a continuously burning pilot light or some form of torch kept handy for igniting them will avoid any unnecessary delay caused by their failure to ignite spontaneously. As in the case with coke fuel, care should be observed that the gases are ignited before attempting to charge.

5. Reduction of Production Capacity With Coal Fuel, With the Usual Operating Methods

The chief difficulty encountered by many gas companies, especially the larger ones, in using bituminous coal for generator fuel in place of coke is the decrease in production capacity ordinarily experienced with coal. Various operators have reported a decrease of 25 or 30 per cent in the possible output of the plant when using coal, as

compared with coke. One reason for this decrease seems to lie in the difference of the resistance of the two fuels to the passage of air under the same blast conditions. The rate of combustion of the fuel, and therefore the rate at which it acquires a gas-making temperature, seems to be roughly proportional to the amount of air passing through the fire in a given time. If the air volume passing is increased by increasing the air pressure, then the combustion is more rapid, and the fuel bed is brought more quickly to the proper temperature for decomposing steam. In most gas plants the blowing capacity is limited, and the initial pressure at the base of the generator is likewise limited by the type of blower used. Consequently, since the coal fuel bed offers more resistance to the passage of air through the fire than does coke, more air is transmitted at the pressure available with a coke fire than with coal, the combustion is more rapid, and during the run the gas production is greater with coke. If it were possible to force the same volume of air through the coal fire in a given time, it seems likely that the volume of gas produced during a given time would more nearly approach that with coke.

Under the usual operating conditions, therefore, it will usually take a blow period longer in proportion to the length of steam run with coal than with coke, in order to bring the fuel up to the same working temperature. On account of the greater amount of volatile matter in the coal, the amount of combustible gas given off during the relatively longer blow period is more than sufficient to maintain the requisite temperatures in the carburetor and superheater; consequently the length of blast period which is suitable for the generator overheats the other chambers, if the gas is entirely burned in them, or necessitates the burning of considerable gas at the stack. Either condition is undesirable and wasteful. With this condition of an excessive production of combustible generator blast gases, it is often found impossible to burn them in the set even with the carburetor blast valve wide open unless the volume of these gases is decreased by partially closing the generator blast valve, or the fuel bed is unduly cooled by excessive use of steam during the steam run. In either case, however, the generator will not attain the desired temperature so quickly. In some plants where there is an excess blowing capacity, it may be advisable to cool the carburetor and superheater by overblowing them rather than to underblow or oversteam the generator. By any of these methods, however, capacity can only be obtained by sacrificing a considerable amount of combustible gas, resulting in a waste of fuel.

6. The Blow-run Cycle for Increasing Capacity

A system of operation was tried out and used successfully, which enables a more thorough heating of the generator, yet retards the overheating of the other chambers and saves some of the volatile matter which would otherwise be wasted. To accomplish this the fire was usually blasted in the regular way for three minutes, the blast pressure being about 17 to 19 inches water pressure under the grate, when both the generator and carburetor blast valves were open. At the end of this blast period the carburetor blast valve (and superheater blast valve when used) were closed. The stack cap was closed, and a blow varying in length from 15 to 30 seconds was made through into the relief holder. At the end of this "blow-run", as it will be herein designated, the generator blast valve was closed, the steam and oil turned on, and the steam run was made in the usual way. The effect of this additional ¼- to ½-minute blast was beneficial, since it brought the fire up to a better gas-making temperature, and yet did not heat up the other chambers to any appreciable degree, since only the sensible heat in the blow-run gases was carried into those chambers which were probably at a higher temperature than the gases, the temperature of which varies from run to run. Since no combustion was taking place in them, the temperature remained stationary, or possibly decreased slightly, which seemed to have a beneficial effect on the subsequent oil cracking. The higher temperature in the fuel bed obtained by this method resulted in a richer blue gas being made during the steam run and this helped to compensate for the relatively low quality of the gas made during the actual blow-run period, though of course some additional oil per 1,000 cubic feet of gas was required to bring the mixture of blue gas and blow-run gas up to standard, beyond that required per 1,000 cubic feet of straight blue gas made by the usual method with coal fuel.

The volume of gas formed during the blow-run when the blast pressure and back pressure on the set were normal was about 10 per cent to 20 per cent of the total make of carburetted gas. In composition the blow-run gas was a rich producer gas,[1] having a calculated heating value of about 155 B. t. u., or about 45 per cent of the heating value of the blue gas formed during the steam run. It contained about 60 per cent of nitrogen and with the nitrogen present in the blue gas, resulted in about 14 to 20 per cent of nitrogen in the finished carburetted gas. It should be noted, however, that while the blow-run

[1] Technically, the term air-gas is used as applied to the gas from a producer when air alone without steam is blown through the fire

cycle introduces some nitrogen into the gas, the oxygen which accompanied this nitrogen in the air, has been entirely removed by the hot fuel bed and converted chiefly into carbon monoxide, a combustible gas. Therefore there is no chance of forming an explosive mixture in the holder by this method since there is no oxygen present in the finished gas. Since the addition of nitrogen is compensated for by the use of more oil and by the formation of richer blue gas during the steam run, so that the heating value of the gas will be the same as it would with the usual methods, there appears to be little real reason for objection to the presence of this additional nitrogen. One of the chief arguments advanced against the presence of inert constituents in the gas is that their presence reduces the temperature possible of attainment when the gas is burned since it is necessary to heat this inert material to the temperature at which the combustion products are discharged from the appliance in which the gas is burned. Computations from the analyses of typical gases produced by the blow-run and by the usual method, show that the difference between the nominal flame temperatures in the two cases is so small that it would be practically negligible even in high temperature industrial appliances and especially so in ordinary domestic appliances where the temperatures to be attained in the materials to be heated are relatively low.

Since with this method more oil is required per run, a greater amount of heat is absorbed from the carburetor and superheater during this period. Thus the gas maker is permitted to burn more of the combustible blast gas in the set without danger of overheating the checker work. This method also enables the operator to increase the capacity of his machine from 20 to 30 per cent over what he could obtain from coal without this cycle, and if the operation is properly timed so that the blow-run is not made of excessive length (not exceeding 30 seconds with normal air blast and back pressure conditions) a distinct advantage should be realized. The amount of gas oil which must be used to carburet the blue gas up to the required standard, will vary in different plants under different conditions. The quality of the oil used, the B. t. u. standard maintained, the weather conditions, the condition of the checker work in the carburetor and superheater, the daily operating time, and many other conditions affect oil efficiency. In the Streator plant, under the conditions existing in the manufacturing and distribution systems, during the late summer, fall and early winter, the Texas oil required to maintain 565 B. t. u. a mile from the plant amounted to between 3.00 and 3.10 gallons per 1,000 cubic feet of gas made (corrected) with this cycle. During the warmer part of the test period, the amount was somewhat less than

this and had more severe weather been experienced, the amount of oil used would doubtless have been somewhat higher. The writers of this paper do not maintain that these oil results could be duplicated in all cases or with inferior oils. Large plants which are unable to obtain all their oil from one source and must at times use mixtures containing inferior oils would doubtless find it difficult if not impossible to maintain the required standard of quality with this amount of oil, even with weather and other conditions as favorable as those obtaining at Streator during the experiments. On the other hand, a plant operating full time with all other conditions favorable might realize even better results. The figures stated are simply for comparative purposes under the conditions with which they were obtained.

The blow-run gives the operator a rather flexible means of controlling the heat balance in his machine. If the temperatures in the carburetor and superheater tend to increase while the generator cools somewhat a little longer blow-run for a few runs, in addition to the regular blasting time, increases the temperature in the generator, and, due to the fact that the increased volume of gas thus produced will require the use of more oil per run, the result is a decrease in the temperatures prevailing in the carburetor and superheater. Similarly decreasing the length of the blow-run has the opposite effect. In case the temperatures of the carburetor and superheater are unduly low when the blow-run cycle is being used, it should be ascertained whether these chambers are being overblown during the blasting period. It may also be advantageous to make the blow period a little longer in some cases rather than to reduce the length of the blow-run. The advantages derived from the blow-run may be summed up as follows: It enables the operator to heat up his generator without wasting the combustible gases produced during the last part of the blow, or overheating his carburetor and superheater in an effort to burn these gases completely within the set. It enables him to make more and better gas during the steam run on account of the higher temperature of his generator at the end of the blow-run. It saves for use a volume of blow-run gas equal to about 20 per cent of the volume of blue gas made during the run, and to increase his make per run by about 20 to 30 per cent. The indications from the tests made have been that the amount of generator fuel used per 1,000 cubic feet of gas made is decidedly lower with this cycle than when no blow-run is used. This naturally follows since the air used during the blow-run serves the double purpose of heating the generator and increasing the total volume of gas made. Considerably less steam is required per 1,000 cubic feet of gas made when employing the blow-run. Care

should be exercised where this cycle is used that it be used with moderation, and where so used it is believed that it will be very advantageous, especially in plants which are operating near to capacity with coke fuel and could not make enough gas with coal fuel by the usual methods.

Even in plants which are not working near to capacity, the blow-run cycle may be of economical advantage over the use of the usual method, with coal fuel. Although a little more oil is required to carburet the gas produced from straight coal with the blow-run method of operation than without the blow-run, the shorter running time to produce a given amount of gas results in less wear and tear on the machine and gives the operator more time to make necessary plant repairs with the same operating force.

7. The Blow-Run With Mixed Coal and Coke

In case a still greater output capacity is desired than can be furnished with straight coal with the blow-run cycle, this may be obtained by the use of a small percentage of coke, up to say 25 per cent, together with a blow-run of suitable length, depending upon the air blast available, quality of gas to be maintained, and hourly make desired. During a run of a few days at the Streator plant with 25 per cent coke and a 30-second blow-run, the hourly output was increased about 6 per cent over that obtained during the days immediately preceding, when 100 per cent coal was used. The blast pressure was practically the same in both cases. During the few days that this combination of conditions was tried, there was no perceptible increase in the amount of oil used per 1,000 cubic feet of gas to maintain practically the same heating value.

8. The Air Purge

A form of blow-run, commonly called an "air purge," has been used in some of the plants visited, but in all cases it has followed the steam run instead of preceding it. The disadvantage of this procedure will be readily seen when the analyses of the blast gases produced just before and just after the run are compared. The blast gases immediately after the run are very lean, since the fire is cold. They contain usually from seven to eight times as much carbon dioxide and nearly 25 per cent more nitrogen, and have a heating value approximately one-half of the heating value of the gases of a blow-run following the regular blast period. However it seems advisable to purge the set of gas by means of the air blast, after every run, if the purge time is made so short that practically no blast gas is blown into the holder. While it is usually presumed that at the end of a run the gas left in the

carburetor and superheater is a lean blue gas, quite often there is an appreciable amount of oil gas present also, as well as some volatile matter from the coal, which it is desirable to save. The quality of this gas depends primarily on the amount of oil added during the run, the time during which oil is admitted, the length of the run after all the oil has been admitted, the temperature of the fuel in the generator, and the amount of steam used during the run. The time required for this air purge will vary from 5 to 15 seconds, and is chiefly dependent on the back pressure. When this back pressure is excessive the time required to purge the set may be so great as to more than offset the advantage of an increase in volume of gas made, which is realized when using the purge under more favorable conditions. The proper length of air purging time is best determined by watching the stack when the lid is raised after a run, and observing the flame. The purging time may be gradually increased until it is observed that most of the rich gas has been driven out of the set previous to raising the stack lid.

The advantages of the blow-run cycle in increasing the producing capacity of the set, and in saving fuel, have been discussed, it being assumed that in a majority of plants there would be no mechanical difficulties to be overcome. This is not, however, the case in some plants, especially the larger city stations. Owing to the rapid growth of the gas output in some communities, several additional gas sets have been added to the original installation, without corresponding increases in the connecting mains joining the sets to the relief holders and intermediate apparatus. It is not uncommon to find a half dozen sets making gas into a main which was originally designed for not more than half that number, and frequently the pressure in the connecting lines may mount up to 30 or 40 inches of water. Since the blast pressure supplied by the blowers at these plants is seldom in excess of 20 to 24 inches of water, it is evident that any attempt to make a blow-run against such a pressure would be futile. It is beyond the province of this paper to discuss the soundness of the engineering policy which has led to such pressures in the collecting mains. It has doubtless been dictated by economic consideration, and the fact which must be faced is that such conditions exist. If it is decided by a company that the use of coal with the blow-run cycle is feasible, it is an economic problem to decide what expenditure is justified to relieve such conditions, in other words, whether the saving from the use of coal would be sufficient to warrant the changes.

Another less serious mechanical difficulty will be found in plants which are equipped with certain interlocking safety devices which

make the operation of the various valves follow a predetermined sequence. These interlocking systems are quite extensive and complicated in some plants while in others there may be but a single interlocking device or none at all. One type of gas machine in very common use has a butterfly valve in the blast main which closes when the stack lid closes. It would not, of course, be possible to make a blow-run with this device in operation, but fortunately it is easily disconnected and arranged so that the butterfly valve will be permanently open, the smaller butterfly valve in the vent to the air remaining permanently closed. While it is not desired to belittle these safety devices, it is not believed that with the usual care in operation the chances of damage to the blast main will be greatly increased, especially if "tell-tale" pipes are led from the inlet sides of the various blast valves to the gas-maker's station, and the usual cardboard heads are installed in the ends of blast mains to protect them in case of explosion.

Since the sequence of operations is different with the blow-run cycle than with the customary method, it is necessary that the operator watch carefully when making his valve changes, until he is thoroughly accustomed to the new procedure. *He must be particularly careful not to leave the carburetor or superheater blast valves or the lower hot valve open while making the blow-run, or any of the blast valves open when making the steam run.* After a few days of operation the gas maker will become thoroughly familiar with this cycle, and no more difficulty will be experienced in handling it than any other cycle.

9. Smoke Prevention

Smoke given off by a gas works or other plant is of course much more objectionable in some localities than in others. Some operators whose plants are unfortunately located in or near residence districts, have feared the creation of a smoke nuisance from the use of bituminous coal as generator fuel more than any other objection which has been raised in connection with it. It is difficult to prevent the escape of smoke at times from any gas plant, regardless of the fuel used. With bituminous coal the possibilities for smoke production are somewhat greater than with coke, but by arrangement of the operating conditions, it is possible to reduce the smoke to a minimum, if not entirely to abolish it. Smoke from coal in a water-gas set, as in boiler plants or other furnaces, arises from incomplete combustion. If conditions are so adjusted that combustion is complete at all times, no smoke will be produced. The greatest smoke difficulty is found when getting a set up to a working condition after a long layover, and it follows that the difficulty is likely to be greater in plants operating but a

small portion of the day than in those running nearly full time. If, after cleaning the fire in the morning after a layover of several hours, a large amount of green coal is put in the generator and blasted, the result is the evolution of a large amount of gas. This gas by itself would perhaps be combustible, but it is diluted by a considerable amount of carbon dioxide formed during the early part of the blasting period by the combination of air with the incandescent fuel below. Also considerable steam is produced by the decomposition of the green fuel and by the evaporation of surface moisture. We have, therefore, a lean gas mixture carrying tarry vapors passing from the generator into the carburetor and superheater, and thence up the stack. The generator gases from coke alone are difficult to ignite at the very beginning of the blast, but being colorless and carrying no tarry vapors, they are not noticed. The problem then with coal fuel is to bring the gases as soon as possible to a requisite degree of richness, so that they will burn. This is accomplished if the temperature of the generator fuel bed is rapidly brought up so high that a large part of the carbon dioxide formed in the combustion zone is reduced by the upper layers of the incandescent fuel, to carbon monoxide. A deep bed of incandescent coke soon produces, upon blasting, combustible gases. The gas maker has two alternatives then, either to start operation with coke and get the fire hot and the generator gases lighted before charging any coal, or if he desires to be entirely independent of coke, he can do so by operating so that considerable coked fuel from the previous day's run remains in the generator after cleaning the fire. To do the latter he must retain a fuel reserve from the preceding day, sufficient to operate on until the gases passing from the generator are rich enough to ignite. The method adopted at Streator, and found to work satisfactorily, was to take only one or two runs off the last coaling before a layover, and when no blow-run cycle was in use, to blast the fire for two minutes before shutting down. No steam run followed the last blast in this latter case. In this manner a hot bed of fuel was left beneath the fresh charge and by the next morning this was largely converted into coke. The generator lid was left slightly ajar over night, and sufficient air entered there to burn the volatile given off by the coal. This helped to maintain the temperature in the carburetor and superheater, but there was no overheating of these chambers. After cleaning the fire in the morning, which usually did not take more than 20 to 40 minutes, a considerable bed of fuel remained for starting operation. This fuel was blasted about 10 minutes. At the end of about 1 to 5 minutes the gases were combustible, and could be lighted in the carburetor. After making one

run, a charge of coal of normal size was made, and on the subsequent blast little or no difficulty was experienced in igniting the gases and burning up all or nearly all of the smoke. After the start-up period but little difficulty should be encountered in overcoming the smoke nuisance if operating conditions are normal, i. e., (a) if the generator is kept hot enough to produce combustible gas during blast, (b) if the checker work is hot enough to ignite the mixture of this gas with the secondary air, as supplied by carburetor blast, and (c) if the combustible gas and carburetor air are properly mixed and in correct proportions.

Some of these conditions may be obtained, when lacking, by a change in the operating procedure. For example, if the heats in the carburetor and superheater are too low, an increase in the amount of generator blast or decrease in the amount of steam used during the run are obvious remedies. Where the mixing of air and blast gases in the carburetor and superheater is poor, it may be remedied in some cases by a rearrangement of the checker work spacing, or by some device in the secondary air inlets to carburetor and superheater, which will cause the incoming air to mix more intimately with the blast gas from the generator. Such cases must have individual attention, and no specific suggestion can be given covering all cases.

10. Prevention of Sticking of Valves Caused by Tar Deposits

The gases leaving the generator when bituminous coal is used, consist not only of carbon monoxide, hydrogen, and carbon dioxide, the usual constituents of water-gas, but they also include varying amounts of hydrocarbons. Some of these are permanent gases, but present also are tarry vapors. These vapors are partially distilled in their passage through the set, and if condensed, deposit as a sticky viscous pitch. This pitch is in evidence at any part of the machine where there is a slight leak, as for example, at the hot valve and the carburetor and superheater blast valves, around the oil spray stuffing box, and occasionally at the generator lid. This pitch is fairly fluid when hot, but when cool is very tough and viscous, and is likely to cause valves to stick very tightly. This need give little trouble if preventive measures are taken. Usually a fairly fluid mixture of lubricating oil and flake graphite, smeared occasionally on the valve stems, will prevent the sticking. Some operators have obtained beneficial results by tapping a small hole in the valve bonnet and pouring a little lubricating oil into the valve through this hole once a day. In general, troubles of this sort are reduced to a minimum when proper temperatures are maintained throughout the set and the weight of charges is not excessive. In plants operating with but short layovers, very little trouble is usually experienced.

11. Control of Clinker From Central District Coals.

Of the half-dozen coals tested at Streator, none has given any clinker difficulties under the conditions of operation used there. Some coals have produced decidedly more fusible clinkers than others, but in all cases these clinkers have been brittle and easily broken up for removal. Owing to the short operating period, averaging about 6.5 running hours per day, only one clean per day was necessary, and in this period the clinker formed was of just about the proper thickness to be removed readily. In a few cases it was found that considerable carbon was fused in with the clinker, but usually the clinker was very free from unburned material.

The nature of the clinker and the ease with which it was handled may be attributed to a considerable degree to the blasting and steaming conditions which were markedly different from those usually employed with coke fuel. The steam used in the generator averaged about 35 pounds per 1,000 cubic feet of gas made. This is somewhat more than is ordinarily considered good practice with good coke. The blast pressure maintained under the grate averaged about 17 inches, and the amount passing through the fire, as indicated by the air meter, amounted to about 1,230 cubic feet per 1,000 cubic feet of gas made. This is decidedly lower than the amount usually regarded as good practice with coke fuel. It was possible to force more air through the fire on only a few occasions, owing to the limited capacity of the turbine blowers available. Had it been possible to force more air through the fire in a given time, it is possible that the clinker would have been of a different character; yet under the existing conditions, fusion seemed to have been fairly complete in most cases. The clinker was, in most cases, well down on the grate, and there was little tendency to the formation of side clinker (edgeings) except in the case of one coal. This coal gave softer clinker than the others, and fusion was seemingly less complete. Where more up runs than down runs were employed, this coal gave considerable side clinker, and this tendency seemed to increase with the proportion of up runs. By alternating the up and down runs, this side clinker did not form. With the other coals it was the usual practice to make two up runs after each coaling, and alternate all other runs. Usually, from two to four pounds more steam per minute were used on up runs than on down runs. In general, it may be said that with coal fuel under all conditions of operation tried, the clinker was much more easily handled than that from the retort coke formerly employed, which was made from a Harlan County, Kentucky, coal. In mixing fuels there is a possible difficulty which

may or may not be encountered, namely, the formation of a clinker from the mixed ashes, much more difficult to handle than the clinker from either of the components. This phenomenon has been observed in some plants and seems entirely logical. The formation of clinker is a chemical as well as a physical process, and the constituents present in the ashes of two fuels may form a combined clinker which is extremely obstinate. In the tests at Streator the coke used, which was retort coke from Harlan County (Kentucky) coal, was considerably more difficult to handle than the clinker from Illinois coal, but the mixture produced a clinker which seemed to lie somewhere between the two in workability, as though the coal ash added components which made the clinker more brittle. Only experiments with a given mixture of fuels could determine what the outcome in a particular case would be. So little is yet known about the relation of ash composition to fusibility, or even about the relation of fusibility to clinker formation in practical operation of a water-gas set, that we have nothing to guide us in the selection of coals or mixtures so far as clinkering properties are concerned except actual trials on a commercial scale.

The clinker formed when operating with a blow-run may be quite different from that obtained with the ordinary method of operation, this difference being due primarily to the difference in temperatures prevailing with and without the blow-run, which has been described previously in this bulletin. This difference in character of the ash or clinker has a marked effect on the hourly output, which is more pronounced as the day proceeds. If, for example, a coal is used which does not readily form a clinker, or whose ash is not readily fusible, it may happen that, with the usual blast employed without a blow-run, no solid clinker will form. In this case ashes will accumulate and in much greater volume than that occupied by clinker. As the volume of ash increases, there is of course less incandescent fuel in the generator, and what is commonly called a "cold generator" is the result. With this lower temperature in the generator, the caking and matting of the generator fuel is more troublesome.

The effect of the accumulation of ashes, along with an increased tendency of the coal to cake and mat together, is an increase in the resistance of the fuel body to the passage of air when blasting. This results in a further decrease in the temperature in the generator. With this condition it will be found that the fire will need cleaning oftener, and the make per hour, or make per run, will rapidly decrease after a few hours running.

This same coal may be used with more blast, or with the blow-run method of operating, and form a clinker which will occupy considerably less space. The matting is less troublesome with the increase in temperature in the generator, and the make per run does not decrease till much later in the day, and after considerably more gas has been made.

SUGGESTIONS FOR OPERATING WITH COAL FUEL

It is impossible to lay down rules for operation which will apply in all cases. The operator beginning the use of coal must experiment a little to find the conditions which best apply to his individual case. The following suggestions are presented as a guide and were applicable to the conditions at Streator.

1. It is well to begin operation with about 50 per cent coal, gradually increasing the percentage of coal in the mixture.

2. Select a coal low in sulphur. Most plants are not equipped to handle more sulphur in the gas than will be produced by 1.5 per cent sulphur in the coal. There are several central district coals having sulphur percentages lower than this.[2]

3. The coal should not be too fine. It should preferably be in lumps about 4 by 6 inches in size. Very fine material should be excluded by forking the coal with the usual coke fork.

4. When starting in the morning do not make double charges of coal. This will result in caking and arching, and the result will be a cold generator, difficult to bring up to heat, usually with excessive smoke production. It is better to have left a deep fuel bed by making a large charge shortly before shutting down the night before. In this case the carburetor can be lighted and a run made before charging any coal. This will give a quicker start, diminish the smoke, and result in a larger make from the start.

5. Build up the generator fire by coal charges of normal size (the same weight as when using coke). Make the charges at intervals of say two runs until the fire is up to the usual working height, that is, just below the take-off connection, then charge at intervals of about five or six runs. Make the charges as rapidly as possible, to avoid loss of time.

6. Proportion the up and down runs and the steam used so that the clinker will come down to the grate where it can be readily removed. The proportion can best be determined by trial. At Streator most of the coals did best with three up runs to two down runs. Usually two successive up runs were made after charging. In some cases, alternate up and down runs seemed more satisfactory.

[2] Cady, G. H., Low-sulphur coals of the central district: Illinois Mining Investigation Bull. 23, 1919

TABLE 1.—*Operating conditions and typical results obtained at Streator*[1]

(Results given in this table represent, in each column, a typical day's run)

Details of practice	100% coal Without blow-run	100% coal Without blow-run	100% coal With blow-run	100% coal With blow-run	83% coal Without blow-run
Size of water-gas set	6 foot	6 foot	6 foot	6 foot	6 foot
Gas made, corrected.....*cu. ft.*	172,000	172,000	183,000	197,000	174,000
Fuel used .....*lbs.*	8,960, Coal A	7,900, Coal B	7,800, Coal C	8,900, Coal A	{ 63,000, Coal C ; { 15,000, Coke
Number of charges	14	12	13	11	13
Average weight of charge.....*lbs.*	640	659	600	810	600
Oil used (Texas 28° Be.).....*gals.*	480	515	553	625	500
Operating cycle	{ 3-minute blast { $3\frac{1}{2}$-minute run	{ 3-minute blast { 4-minute run	{ 3-min. blast { $\frac{1}{2}$-min. blow run { $3\frac{1}{2}$-min. steam run	{ 3-minute blast { $\frac{1}{4}$-min. blow run { $3\frac{3}{4}$-min. steam run.	{ 3-minute blast { 4-minute run
Make per run.....*cu. ft.*	2,606	2,831	3,660	3,339	3,053
Gas made per running hr.....*cu. ft.*	21,235	23,468	28,707	26,620	24,860
Fuel used per M cu. ft. gas made..*lbs.*	52	46	$42\frac{1}{2}$	45	45
Oil used per M cu. ft. gas made..*gals.*	2.79	2.97	3.02	3.17	2.87
B.t.u.'s one mi. from plant.....	565	578	565	583	560
Gas made per sq. ft. grate area per hr. .....*cu. ft.*	1,700	1,877	2,296	2,129	1,990
Total operating time.....*no. runs*	8.1 hrs., 66 runs	7.33 hrs., 59 runs	6.34 hrs., 50 runs	7.4 hrs., 59 runs	7 hrs., 57 runs
Air used per M cu. ft. gas made.*cu. ft.*	1,350	1,272	1,080	1,160	1,180
Air used during blow run.....*cu. ft.*	0	0	500	270	0
Blast pressure .....*ins. of water*	17 to 18	17 to 18	18 to 19	18 to 19	17 to 18
Steam used per M cu. ft. gas made.*lbs.*	41	43.3	32	37.7	44
Temperature of carburetor..*degrees F.*	1,400	1,340	1,360	1,350	1,300
Temperature of superheater.*degrees F.*	1,300	1,240	1,280	1,340	1,300
Gas purged out of set by air blast after each run, into holder..*seconds*	5 to 6	5 to 6	6	6	6
Gas burned at stack on blasting.....	Very little	Very little	Some, latter part of day	Very little	A little
Up and down runs used.....	2 ups to 1 down	2 ups to 1 down	Alternate up and down	Alternate except after charging, when 2 ups were made	Alternate up and down.
Side clinker	Yes ; clinker on grates was not hard ; considerable ashes present	None ; clinker was hard and on grates	None ; all on grates ; hard but easily removed	None ; clinker all on grates ; hard, easily removed	None ; clinker hard and down on grates ; fire easily cleaned

[1] In the reading matter of this bulletin the deductions and results are given only after consideration of all the data obtained during the experiments at Streator. In the table, however, each column shows the results and operating conditions of a single day. These particular days were selected because they give, in most particulars, average results. The results are given merely for the purpose of comparing one set of conditions with another. *They are not set forth as being necessarily reproducible in all plants under all conditions.*

7. The length of blowing and steaming times will depend upon the blast and steam available. In general, try to so proportion the blow and run that the generator, carburetor, and superheater will attain the proper working temperatures at the same time. With coal there is a tendency for the carburetor and superheater to become too hot before the generator is hot enough. This is usually partly overcome by one or more of the following methods: (a) By allowing some gas to burn at the stack; (b) by over-steaming the generator and thereby diminishing the amount of combustible gas formed (this, however, cools the generator still more); (c) by over-blowing the carburetor and superheater; and (d) by the use of the blow-run cycle. Of these methods, the writers believe that (d) is the most economical and results in the largest set capacity. If this cycle is not desired, then the use of (c) or (a) seems generally the least objectionable, where conditions permit.

8. It is usually most satisfactory in the long run to use reduced steam and oil during the first four or five runs, while bringing up the heats.

9. When adopting the blow-run method, care should be taken to make the blow-run of only sufficient length to maintain the proper heat balance in the set and to obtain the desired make of gas without an excessive expenditure of oil.

10. Be sure that the *lower* hot valve and carburetor and superheater blast valves are closed before shutting the stack cap to make the blow-run. Do not reverse the hot valves while making the blow-run. Close the generator blast valve before turning on the steam to make the regular steam run.

11. If the carburetor and superheater remain cold when the blow-run cycle is used, make sure that they are not being over blown during the blast period. Use only enough carburetor and superheater blast to burn the combustible gases in the set. It may be advisable to lengthen the blow and increase the amount of steam, rather than shorten the blow-run, if capacity is desired.

12. There is considerably more tar produced with coal than with coke fuel. The average increase has not been ascertained. Care should be taken that the tar is removed from the gas before it reaches the purifiers. The operation of the tar extractor, or shavings scrubber, especially should be watched.

13. The flanges on the bottoms of the hot valves should be removed occasionally to remove any deposits of carbon or carbonized tar. The presence of such deposits is indicated by the failure of the valves to close tightly.

14. During layover periods, it is usually advisable to leave the generator lid slightly open or "cracked." This seems to assist in heating the generator and in burning off any carbon which may have been deposited in the checkerwork of the carburetor and superheater.

15. There is a tendency for hot valves and oil spray stems to stick during layover periods. This may be remedied by smearing the stems with a mixture of lubricating oil and graphite. The introduction of oil into the hot valve bonnets also seems to assist.

16. A tendency is noticeable for the fuel to burn down more rapidly around the generator wall than in the center. In order to avoid the by-passing of air and steam between the fuel and the generator wall, and to equalize the rate of subsidence of the surface of the fuel bed, the use of a fuel spreader when charging, is recommended, especially in the operation of the larger sets

CONCLUSIONS

The operating conditions with coal, which have been described, have been adopted for regular operation in the Streator plant. The use of coal in that plant is preferred, not only by the superintendent, but also by the operating force, since it has proven for that plant economically advantageous, has given a larger hourly output than the coke formerly used, and has actually made working conditions easier for the men employed, and has given the superintendent the opportunity to accomplish more repairs and yard work with the same force.

The small size of the Streator plant and the large over-capacity of its generating equipment make a prediction of fuel and oil efficiencies attainable in a larger plant operating near its capacity very difficult, if not impossible. This was recognized from the beginning of the tests. The plant is actually making gas only slightly over one-fourth of the 24-hour day. During the layover periods, a certain amount of fuel is being consumed without any return in gas made; this makes the fuel per 1,000 cubic feet of gas relatively high. Likewise, the set must be brought up to working condition after a layover; this involves excessive fuel consumption and reduces the oil efficiency, since the oil can not be properly fixed until the temperature in the fixing chambers is suitable. This usually consumes an hour or so, which is a very large percentage of the working day.

While these deficiencies in a test of this kind are recognized, the investigations have served to show operating methods and tendencies, to indicate the availability of certain central district coals for this purpose, and to indicate to a certain extent what may be expected on a larger scale operation. The results actually obtained and the details of operation, including chemical studies of various stages of the process, will appear in a later publication.

It is hoped that experimental work may be undertaken in the near future at a plant operating nearer full capacity, in order that all the possibilities of coal as generator fuel may be realized. In the meantime it is hoped that gas operators may be encouraged to try the methods outlined in this paper in their own plants. The writers of this paper will be pleased to render any assistance possible to those requiring it.

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[1] Bulletins listed in italics apply directly to the problem of use of central district bituminous coals in place of eastern coal and coke.